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Long-Range Forecasting and Climate Research

Comparison of corrected sea surface and air temperature for the globe and the hemispheres, 1856-1988

by

C.K. Folland and D.E. Parker

Presented at the 13th Annual Climate Diagnostics Workshop, Boston, USA.
31 Oct-4 Nov 1988

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Met O 13 (Synoptic Climatology Branch)
Meteorological Office
London Road
Bracknell
Berks RG12 2SZ
UK

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COMPARISON OF CORRECTED SEA SURFACE AND AIR TEMPERATURE FOR THE GLOBE AND THE HEMISPHERES, 1856-1988

C K FOLLAND[1] and D E PARKER

Meteorological Office, Bracknell, Berkshire, England RG12 2SZ

Introduction. There is considerable interest in variations of climate during the instrumental period. Studies of these variations can cast light on the natural variability of climate, and on climatic mechanisms including those of the greenhouse effect, and are needed for empirical long-range forecasting research. Sea surface temperature (SST) is particularly important. Unfortunately historical SST data are not only incomplete but suffer from seriously changing biases. There are also substantial disagreements between the global and hemispheric bias estimates of Jones et al (1986) and Folland et al (1984) for SST data before 1905. We summarise recent research into these biases and provide a new set of corrections. An earlier version of this approach has been used in Bottomley et al (1989).

Results. Fig. 1 shows uncorrected seasonal SST and corrected night marine air temperature (NMAT) anomalies averaged over the globe for 1856 to (July-Sept) 1988. The reference period is 1951-80. The corrections that have been applied to the NMAT data are to compensate for changes in deck elevation and for changed observing practices in World War II (see Figure caption), but are slightly different from those described in Folland et al (1984). A sudden change in the difference between the uncorrected SST and corrected NMAT anomalies can be seen in Fig. 1 around 1942, much as shown in Barnett (1984) and Folland et al (1984).

Fig. 2 shows a spectral analysis of uncorrected SST anomalies for 1901-1941 for the whole N Atlantic. A large spectral peak can be seen at periods near one year, i.e. there appears to be a strong annual cycle relative to the 1951-80 reference period. Correspondingly, we find that many series of extratropical SST anomalies that have been band-pass filtered to pass periods centred on one year show enhanced variance until around 1942 (e.g. Fig. 3, top curve). Only in areas of little real annual cycle near the equator is this behaviour absent. The change around 1942 is abrupt in the extratropical N. Hemisphere. We attribute the changes in the annual cycle to a worldwide change in the instrumentation used to measure SST. It is known that the predominant instrument used before the second World War was the uninsulated or partially insulated sea bucket. It is thought that around 1941-2 engine intake measurements became predominant because of the exigencies of war. These will show a reduced annual cycle of SST relative to those derived from uninsulated buckets because the seasonally varying effects of evaporation and sensible heat transfer from the bucket walls have no counterpart in engine intake measurements. Documentation suggests that after 1945 engine intake techniques retained their prominence or shared it with insulated buckets, though it is known that some uninsulated buckets were used for many years e.g. by the UK.

The top curve of Fig. 3 shows, for 1858-1984 for the latitude band 30°N-40°N, a 15 year running ratio of the variance of uncorrected SST anomalies near the one year time scale to the total variance. The data for before about 1880 are less complete so the ratio is less reliable then. A large reduction in the ratio can be seen centred around 1942. A correction

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1 currently at Climate analysis Center, National Meteorological Center, Washington, D C, 20233

technique has been devised which takes advantage of this behaviour. It combines an a priori component, i.e. a physical model of the heat exchange from uninsulated buckets, and an a posteriori component, i.e. a statistical requirement that the above variance ratio for the period before 1942 should be as similar as possible to its value in 1951-80. Thus the correction procedure attempts to correct the SST data relative to the data mix in 1951-80. It does not, in principle, supply absolute corrections.

The model was used to calculate corrections for uninsulated bucket SST on 5° latitude x longitude and monthly resolution for many latitude zones away from the equator. The corrections varied according to the assumed exposure time as well as the size of the uninsulated bucket and the assumptions about atmospheric conditions on a ship's deck relative to those in standard 1951-80 climatologies. Climatological data for each calendar month and 5° x 5° area were used in the derivation of the boundary conditions for the model. Fig. 3 includes the results of applying test-corrections to pre-1942 data in the zone 30°N-40°N. As the modelled exposure time of the bucket was increased, all other parameters being held fixed, the variance ratio first decreased to a minimum (at about 1.5 minutes exposure time for this case) and then increased as exposure time increased further. The latter behaviour indicates that the data have been overcorrected because the assumed exposure time was too long. The exposure time yielding minimum variance ratio was taken as optimal. Estimation of the optimal exposure time must be carried out for entire zonal belts because real interannual and interdecadal climatic variations in the annual cycle of SST are most likely to occur in local zones of longitude. Reasons for this include changes in the phase or intensity of atmospheric long waves and in regional oceanic processes. Nevertheless, the corresponding corrections can be retrieved on a 5° x 5° space scale. Inspection of Fig. 3 and similar diagrams for other latitude zones away from the equator shows that the enhanced annual-cycle variance observed in the uncorrected data is consistently and strongly reduced throughout the record before 1942 using optimal exposure times provided by this technique.

For each latitude belt, the optimal exposure time was estimated separately for 1861-90, 1881-1910, 1901-30 and 1911-40 for a variety of model assumptions (on e.g. bucket size) by minimising the variance ratio as described above. Using analysis of variance tests, it was found that, for a given set of model assumptions, the same exposure time could be used for all available latitude zones of the global ocean that show an appreciable annual cycle. It was then assumed that the same exposure time could be used everywhere for a given set of model assumptions, including in equatorial regions. Although this universal optimal exposure time depended substantially on the model assumptions e.g. being longer for a larger bucket which cools (or occasionally warms) more slowly, the consequent optimal corrections produced by the model were quite similar in a given 5° x 5° region and calendar month. The variations that did occur were mostly considerably less than a typical mean annual correction of 0.25-0.5°C. However, the universal optimal exposure time for a given set of model assumptions tended to increase between the 19th and 20th Century portion of the record. This was assumed to be mostly because the later ships moved more quickly, strengthening the effective wind, so that in the model the bucket needed to cool for a little longer for a given ship's speed if the amplified annual cycle of heat loss was to be reproduced. If an appropriate sequence of estimated ship speeds was used in the model the same optimal exposure time could be applied throughout the record, and the optimal corrections up to 1890 were then typically one third smaller than those after 1910. The final corrections for a given location and calendar

month were computed by averaging the optimal corrections for a range of reasonable assumptions about bucket size and degree of shelter on deck, but with slow (4 m/sec) and fast (7 m/sec) ships' speed for 1856-90 and 1911-41 respectively. This change in mean ships' speed is only a first estimate of the effects of the transition from sail to steam. The corrections for a given calendar month were interpolated linearly in time to yield corrections for 1891-1910. Although the new corrections are much more complex, their globally averaged value in the late nineteenth century, about 0.26°C, is only slightly less than the constant value of 0.3°C used in Folland et al (1984).

Fig. 4 shows the corrections calculated for December 1856-1890. The corrections are quite large near the equator because differences between saturation vapour pressures at the SST and atmospheric vapour pressures allow substantial rates of evaporation from the bucket. As expected, the corrections there are similar there throughout the year. The mean annual magnitude of the corrections is broadly consistent with the results of an extensive worldwide comparison of bucket (believed to be mostly uninsulated) and engine intake data performed by Walden (1966). The comparison is best equatorwards of 40°N or S.

Fig. 5 compares decadal running differences between air temperature anomalies observed on islands distributed worldwide and nearby corrected SST anomalies. The reference period is 1951-80. The number of islands varies from about 10 in 1870 to about 55 in recent decades. The air temperature data have been kindly provided by Dr P Jones (Climatic Research Unit, Univ. of E. Anglia, Norwich, UK). The differences are statistically insignificant in both hemispheres in the late nineteenth century while between 1900 and 1940 the land air temperature anomalies are between 0.1°C and 0.2°C higher than the SST anomalies. When the SST and NMAT data are compared in similar regions surrounding the above islands, their differences are found to be statistically insignificant in all decades.

Fig. 6 shows time series of corrected, smoothed, seasonal SST and NMAT anomalies, relative to 1951-80, for the two hemispheres for 1856 to (July-Sept) 1988. The agreement between SST and NMAT was not forced by the correction procedures and is therefore powerful evidence for their validity. Work is underway to test the sensitivity of these results to a similar correction procedure that uses models of partially insulated (wooden, leather etc) buckets.

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Jones P D, Wigley T M L, and Wright P B (1986) Nature, 322, 430-434
Walden H, (1966) Deutsche Hyd., Zeits., 19, 1, 21-28

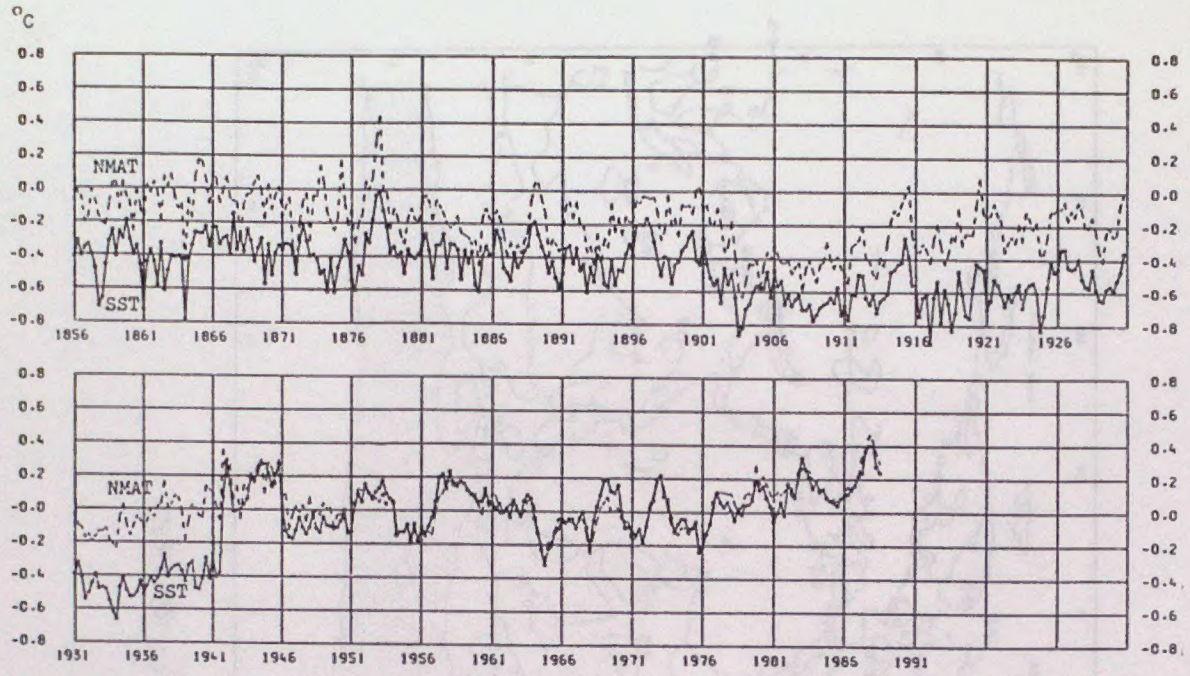

Figure 1. Global seasonal anomalies of uncorrected SST and corrected* night marine air temperature, 1856 to (July-Sept)1988.

* INSTRUMENTAL CORRECTIONS APPLIED TO NMAT:-0.15 <1891:LINEAR RISE TO 1911 THEN NIL TO MAR40:-0.1 TO DEC41: NIL FROM OCT 1945 ALSO -0.5 1942-SEP45 BUT -0.6 IN ATL>20N.-0.9 IN PAC>25N&20-25N.W OF 165W.1942-SEP45 BAD MAT ANOMALIES 1876-93 IN MEDITERRANEAN & N.INDIAN OCEAN REPLACED BY SST ANOMALIES

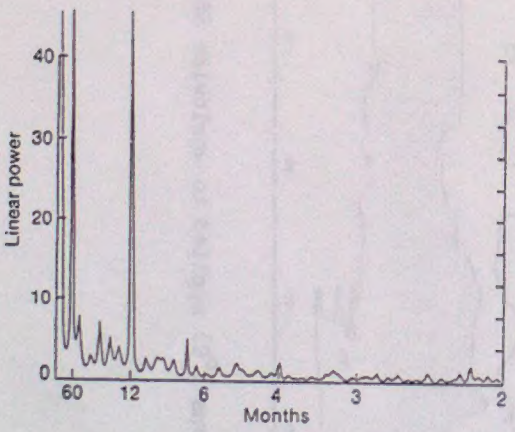

Figure 2.
Spectral analysis of uncorrected SST anomalies for N.Atlantic, 1901-1941.

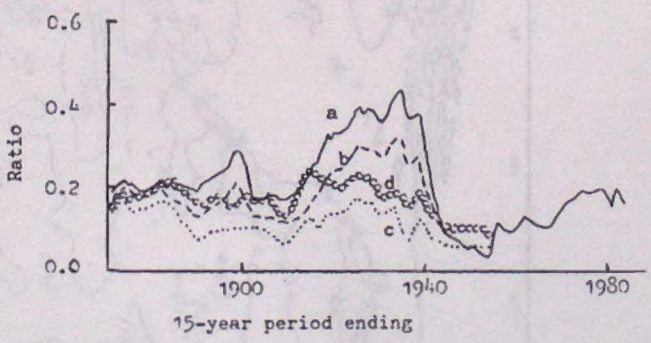

Figure 3.
15-year running ratio of annual-cycle variance to total variance of monthly SST anomalies (w.r.t.1951-80 climatology) for the belt 30°N to 40°N, 1858-72 to 1970-84.

a. Uncorrected.
b. Corrected up to 1941 assuming ½ minute exposure time.
c. As b. but 1½ minutes' exposure time
d. As b. but 3 minutes' exposure time.

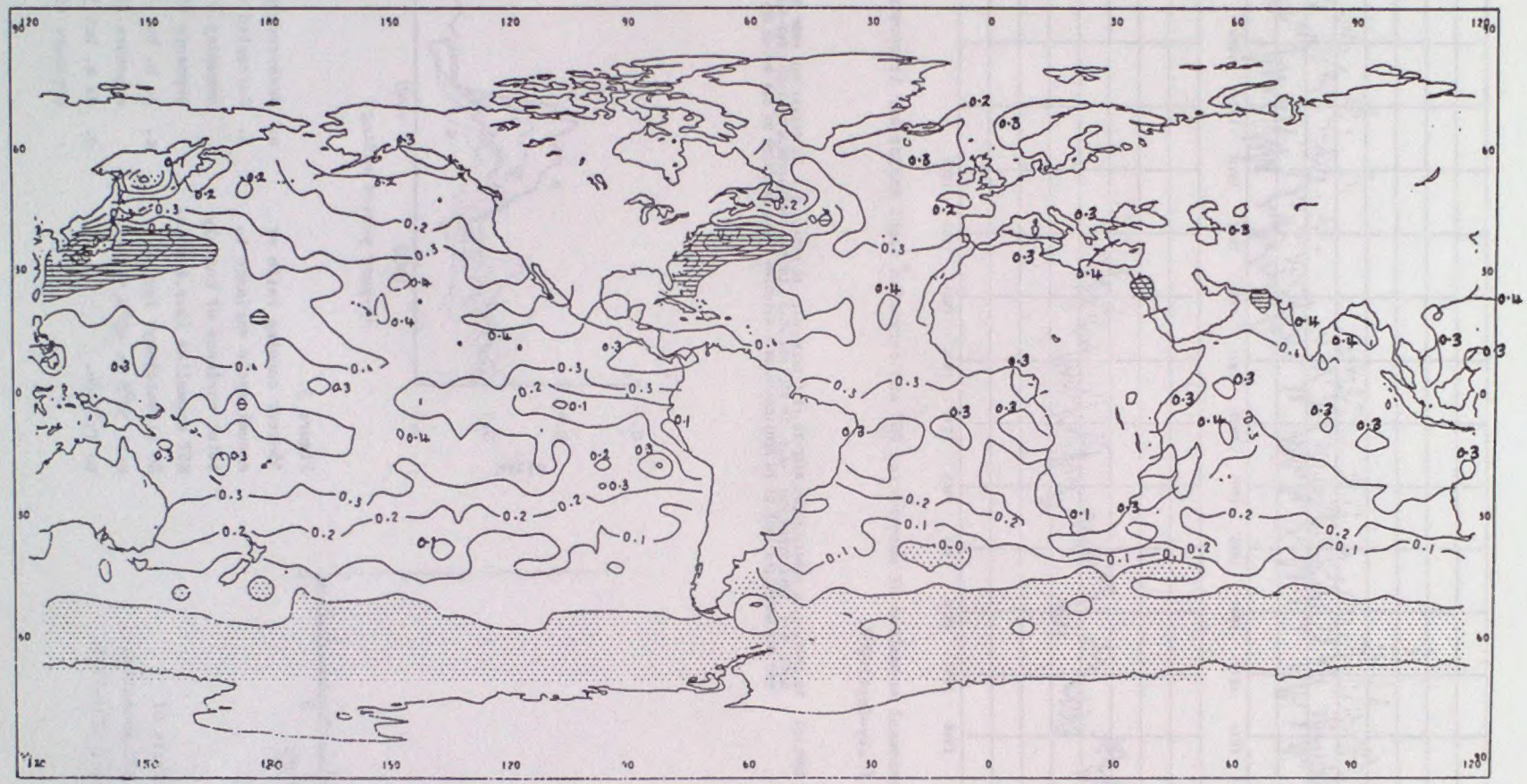

Figure 4. Corrections (°C) applied to worldwide SST anomalies in December, 1856-1890.

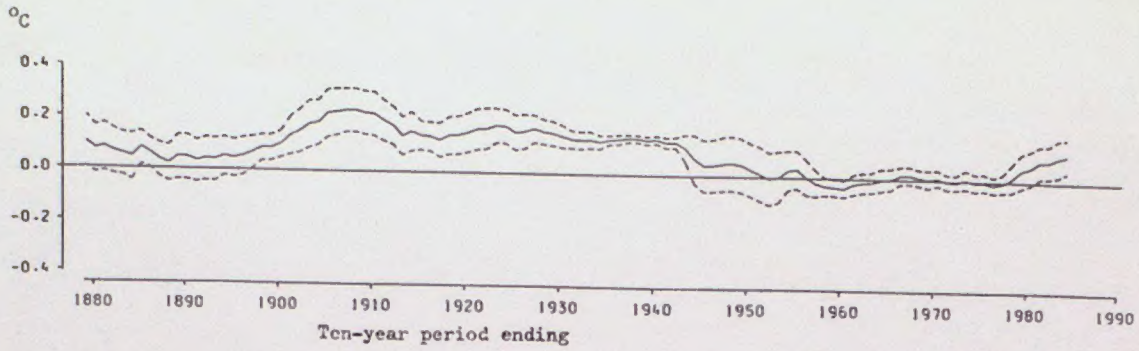

Figure 5. Worldwide average differences between decadally-averaged anomalies of island air temperature and of nearby corrected SST, 1870-79 to 1975-84. Estimates of +/- 2 standard errors are shown by the dotted lines.

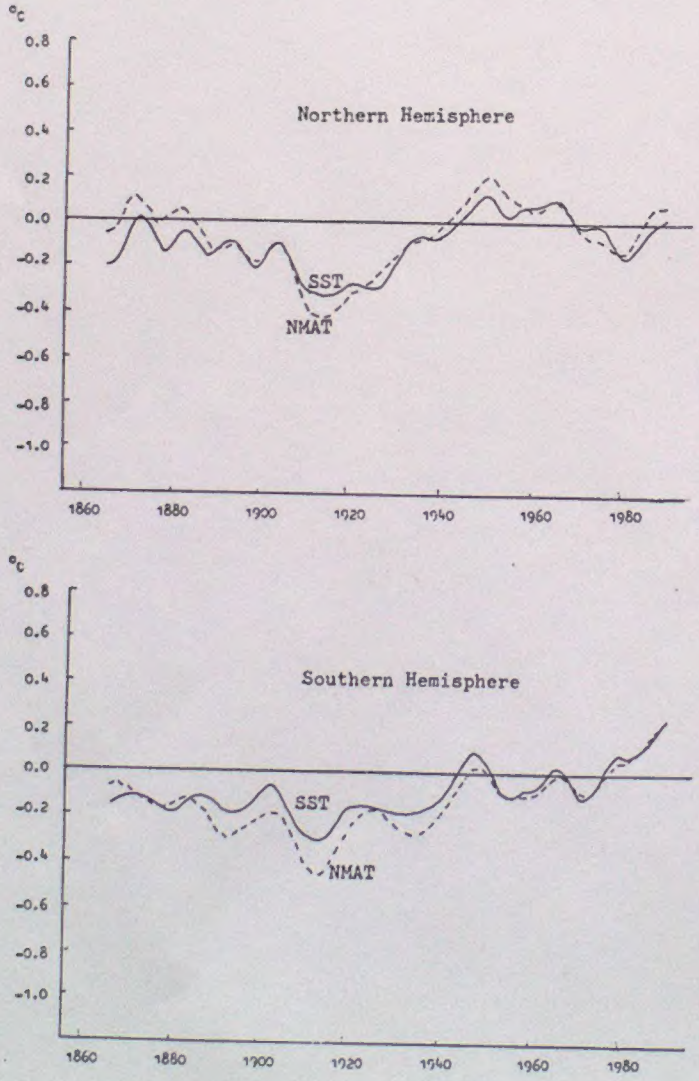

Figure 6.

Smoothed corrected SST and NMAT anomalies for the Northern and Southern Hemispheres, 1856 to (July-Sept)1988. Triangular smoothing eliminates fluctuations with periods less than about 5 years. Values are plotted against the end-date of the smoothing interval.

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